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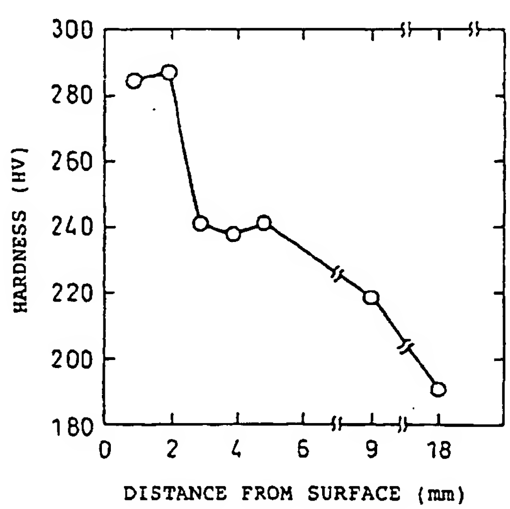
(54) BAR OR WIRE PRODUCT FOR USE IN COLD FORGING AND METHOD FOR PRODUCING THE SAME

(57) The present invention provides a steel bar or wire rod for cold forging excellent in ductility after spheroidizing annealing and capable of preventing the occurrence of cracking in the steel material during cold forging, which cracking has so far been a problem when manufacturing machine structural components by cold forging, and a method to produce the same. Specifically, a steel bar or wire rod for cold forging according to the present invention has a chemical composition comprising, in mass, 0.1 to 0.65% of C, 0.01 to 0.5% of Si, 0.2 to 1.7% of Mn, 0.001 to 0.15% of S, 0.015 to 0.1% of Al, 0.0005 to 0.007% of B, and the restricted elements of 0.035% or less of P, 0.01% or less of N and 0.003% or less of O, with the balance consisting of Fe and unavoidable impurities, and is characterized in that: the area percentage of ferrite structure is 10% or less at the portion from the surface to the depth of 0.15 time the radius of the steel bar or wire rod; the other portion consists substantially of one or more of martensite, bainite and pearlite; and further the average hardness of the portion from the depth of 0.5 time its radius to its center is less than the hardness of its surface layer (the portion from the surface to the depth of 0.15 times the radius) by HV 20 or more.

Fig.1



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Description

Technical Field

[0001] The present invention relates to a steel bar or wire rod, for cold forging, used for manufacturing machine structural components such as those of cars and construction machines and a method to produce the same. More specifically, the present invention relates to a steel bar or wire rod, for cold forging, excellent in ductility and suitable for the cold forging by heavy working and a method to produce the same.

Background Art

[0002] Carbon steels for machine structural use and low alloy steels for machine structural use have conventionally been used as structural steel materials for manufacturing machine structural components such as those of cars and construction machines. Machine structural components such as bolts, rods, engine parts and driving system components for cars have so far been manufactured from these steel materials mainly through hot forging and machining processes. A recent trend, however, is that the above processes are replaced with a cold forging process for the sake of enhanced productivity and other advantages. In a cold forging process, cold forging is usually applied to hot rolled steel materials after spheroidizing annealing (SA) is applied to secure cold workability. A problem in the cold forging is, however, that the steel materials are hardened by working and their ductility is lowered, resulting in the occurrence of cracks and a shorter service life of metal dies. In case of heavy cold forging in particular, cracking during cold forging, namely the insufficient ductility of steel materials, is often the main hindrance to changing the process from hot forging to cold forging.

[0003] Meanwhile, since the spheroidizing annealing (SA) requires high temperature heating and a long retention time of steel materials, it not only requires a heat treatment facility such as a reheating furnace but also consumes energy for the heating, and therefore the process accounts for a large proportion of the total manufacturing cost. To cope with this, various technologies have been proposed from the viewpoints of productivity improvement, energy saving, etc.

[0004] Some examples are as follows: Japanese Unexamined Patent Publication No. S57-63638 proposes a method to shorten the time for spheroidizing annealing and obtain a steel wire rod excellent in cold forging by cooling a steel material to 600°C at a cooling rate of 4°C/sec. or higher after hot-rolling to form a quenched structure and then applying spheroidizing annealing to the steel material covered with scale in an inert gas atmosphere; Japanese Unexamined Patent Publication No. S60-152627 proposes a method to enable quick spheroidizing by regulating finish rolling conditions, rapidly cooling the steel material after the rolling and forming a structure in which fine pearlite, bainite or martensite is intermingled with finely dispersed pro-eutectoid ferrite; Japanese Unexamined Patent Publication No. S61-264158 proposes a method to lower the steel hardness after spheroidizing annealing by improving steel chemical composition, namely obtaining a low carbon steel having a reduced P content of 0.005% or less and satisfying $Mn/S \geqq 1.7$ and $Al/N \geqq 4.0$; and Japanese Unexamined Patent Publication No. S60-114517 proposes a method to eliminate a softening annealing process before cold working by applying a controlled rolling.

[0005] All these conventional technologies aim at improving or eliminating the spheroidizing annealing before cold forging and do not aim at improving the insufficient ductility of steel materials, which is the main hindrance to changing the process from hot forging to cold forging in the manufacture of machine components requiring heavy working.

Disclosure of the Invention

[0006] In view of the above situation, the object of the present invention is to provide a steel bar or wire rod for cold forging excellent in ductility after spheroidizing annealing and capable of preventing the occurrence of cracking in the steel material during cold forging which has, so far, been a problem when manufacturing machine structural components by cold forging after applying spheroidizing annealing to a hot-rolled steel bar or wire rod, and a method to produce the same.

[0007] The inventors of the present invention discovered, as a result of investigating the cold workability of a steel bar or wire rod for cold forging, that it was possible to obtain a steel bar or wire rod for cold forging excellent in ductility after spheroidizing annealing by hardening only the surface layer of a steel bar or wire rod having a specific chemical composition and softening the structure of its center portion.

[0008] The gist of the present invention, which has been established on the basis of the above finding, is as follows:

(1) A steel bar or wire rod for cold forging excellent in ductility after spheroidizing annealing, having a chemical composition comprising, by mass,

0.1 to 0.65% of C,
0.01 to 0.5% of Si,
0.2 to 1.7% of Mn,
0.001 to 0.15% of S,
0.015 to 0.1% of Al,
0.0005 to 0.007% of B, and
the restricted elements of
0.035% or less of P,
0.01% or less of N and
0.003% or less of O,
with the balance consisting of Fe and unavoidable impurities, characterized in that: the area percentage of ferrite structure is 10% or less at the portion from the surface to a depth of 0.15 times the radius of the steel bar or wire rod; the other portion consists substantially of one or more of martensite, bainite and pearlite; and further the average hardness of the portion from the depth of 0.5 times its radius to its center is less than the hardness of its surface layer (the portion from the surface to the depth of 0.15 time the radius) by HV 20 or more.

(2) A steel bar or wire rod for cold forging excellent in ductility after spheroidizing annealing according to the item (1), characterized by further containing 0.2 mass % or less of Ti.

(3) A steel bar or wire rod for cold forging excellent in ductility after spheroidizing annealing according to the item (1) or (2), characterized by further containing, by mass, one or more of

3.5% or less of Ni,
2% or less of Cr and
1% or less of Mo.

(4) A steel bar or wire rod for cold forging excellent in ductility after spheroidizing annealing according to any one of the items (1) to (3), characterized by further containing, by mass, one or both of

0.005 to 0.1% of Nb and
0.03 to 0.3% of V.

(5) A steel bar or wire rod for cold forging excellent in ductility after spheroidizing annealing according to any one of the items (1) to (4), characterized by further containing, by mass, one or more of

0.02% or less of Te,
0.02% or less of Ca,
0.01% or less of Zr,
035% or less of Mg,
0.1% or less of Y and
0.15% or less of rare earth elements.

(6) A steel bar or wire rod for cold forging excellent in ductility after spheroidizing annealing according to any one of the items (1) to (4), characterized in that the austenite grain size number according to Japanese Industrial Standard (JIS) is 8 or larger at the portion from the surface to the depth of 0.15 times the radius of the steel bar or wire rod.

(7) A method to produce a steel bar or wire rod for cold forging excellent in ductility after spheroidizing annealing, characterized by finish-hot-rolling a steel having a chemical composition specified in any one of items (1) to (5) in a manner to control its surface temperature to 700 to 1,000°C at the exit from the final finish rolling stand and then subjecting it to at least one or more process cycles consisting of rapid cooling to a surface temperature of 600°C or below and recuperation by its sensible heat to a surface temperature of 200 to 700°C, so that the area percentage of ferrite structure is 10% or less at the portion from the surface to the depth of 0.15 times the radius of the steel bar or wire rod, the other portion consists substantially of one or more of martensite, bainite and pearlite, and further the average hardness of the portion from the depth of 0.5 times its radius to its center is less than the hardness of its surface layer (the portion from the surface to the depth of 0.15 times the radius) by HV 20 or more.

(8) A steel bar or wire rod for cold forging excellent in ductility, characterized in that the steel bar or wire rod is

subjected to spheroidizing annealing like any one of the items (1) to (6), the degree of spheroidized structure defined by JIS G 3539 is within No.2 at the portion from the surface to the depth of 0.15 time the radius of the steel bar or wire rod and, in addition, the degree of spheroidized structure is within No. 3 at the portion from the depth of 0.5 time its radius to its center.

(9) A steel bar or wire rod for cold forging excellent in ductility according to the item (8), characterized in that the ferrite grain size number under JIS is 8 or larger at the portion from the surface to the depth of 0.15 times the radius of the steel bar or wire rod.

Brief Description of the Drawings

[0009]

Fig. 1 is a graph showing the relationship between the distance (mm) from the surface and the hardness (HV) of a steel bar for cold forging (C: 0.48%), according to the present invention, having the diameter of 36 mm.
Fig. 2(a) is a micrograph (x 400) of the surface of a steel bar and Fig. 2(b) is another of its center.
Fig. 3(a) is a micrograph (x 400) of the surface of the steel bar shown in Fig.1 after spheroidizing annealing, and Fig. 3(b) is another of its center.
Fig. 4 is a schematic illustration showing an example of a rolling line employed in the present invention.
Fig. 5(a) is a diagram showing CCT curves to explain the structures of the surface layer and the center portion of a steel bar or wire rod and Fig. 5(b) a sectional view showing the structures of a steel bar or wire rod after cooling and recuperation.

Best Mode for Carrying out the Invention

[0010] The present invention is explained in detail hereafter.

[0011] In the first place, explained are the reasons why the steel chemical composition is defined as above to realize the structure and the mechanical properties such as hardness and ductility of a steel bar or wire rod for cold forging envisaged in the present invention.

[0012] C is indispensable for increasing steel strength so as to be suitable for machine structural components and, with a C content less than 0.1%, the strength of the final products is insufficient but, with a C content in excess of 0.65%, the ductility of the final products is deteriorated. The C content is, therefore, limited to 0.1 to 0.65%. In particular, it is preferable to control the content of C in the range from 0.2 to 0.4% in case of bolts and other mechanical components requiring quenching, from 0.1 to 0.35% in case of those requiring carburization quenching, and from 0.3 to 0.65% in case of those requiring induction quenching.

[0013] Si is added as a deoxidizing agent and for increasing the strength of final products through solid solution hardening. A content of Si below 0.01% is insufficient for obtaining the above effects but, when it is added in excess of 0.5%, these effects do not increase any more and, adversely, ductility is lowered. For this reason, the content of Si is defined as 0.01 to 0.5%. It is, however, preferable to set an upper limit of the Si content at 0.2% or lower, more preferably, at 0.1% or lower.

[0014] Mn is effective for increasing the strength of the final products through the enhancement of hardenability but, with a content of Mn less than 0.2%, a sufficient effect is not obtained and, with its addition in excess of 1.7%, the effect becomes saturated and, adversely, ductility is lowered. The Mn content is, therefore, limited to 0.2 to 1.7%.

[0015] S is inevitably included in steel and exists there in the form of MnS. Its content is defined in the present invention as 0.001 to 0.15% since S contributes to the improvement of machinability and the formation of fine crystal structure. However, since S deteriorates ductility and thus is detrimental to cold forming work, it is preferable to limit its content to 0.015% or lower, more preferably, to 0.01% or lower, when machinability is not required.

[0016] Al is effective as a deoxidizing agent. It is also effective for fixing solute N in steel in the form of AlN and securing solute B. With an excessive content of Al, however, an excessive amount of Al_2O_3 is formed, resulting in the increase of internal defects and the deterioration of cold workability. The content of Al is limited in the present invention to the range from 0.015 to 0.1% for the above reason. Note that it is preferable to control the Al content to 0.04 to 0.1% when Ti, which serves to fix the solute B, is not added.

[0017] B precipitates in the form of $Fe_{23}(CB)_6$, which is a chemical compound of B, at the α/γ interface during the cooling process after spheroidizing annealing, contributing to softening the steel and enhancing cold workability by accelerating the growth of ferrite and broadening the distances among spheroidal carbides. Besides, the solute B precipitates at grain boundaries to enhance hardenability. For these reasons, the content of B is defined as 0.0005 to 0.007%.

[0018] P is inevitably included in steel, but it causes grain boundary segregation and center segregation, deteriorating

ductility. It is, therefore, desirable to limit the content of P to 0.035% or less, or, more preferably, 0.02% or less (including 0%).

[0019] N is also inevitably included in steel. Since it is a detrimental element which reacts with B to form BN and lowers the effect of B, its content has to be 0.01% or less or, preferably, 0.007% or less.

[0020] O is inevitably included in steel, too, and deteriorates cold workability by reacting with Al to form Al_2O_3. It is therefore desirable to control its content to 0.003% or lower or, preferably, 0.002% or lower (including 0%).

[0021] The basic chemical composition of steel intended for the present invention is as described above. Further, in the present invention, Ti is added to fix N in the form of TiN and make N harmless. Since Ti is also effective as a deoxidizing agent, it is added to 0.2% or less, as deemed necessary. Further, one or more of Ni, Cr and Mo are added for the purpose of increasing the strength of final products through the enhancement of hardenability and other effects. An addition of these elements in great quantities, however, raises steel hardness through the formation of bainite and martensite at the center portion of an as hot-rolled steel bar or wire rod, and is not economical. The contents of these elements, therefore, are limited as follows: 3.5% or less for Ni, 2% or less or, preferably, 0.2% or less for Cr, and 1% or less for Mo.

[0022] In addition, for the purpose of controlling the crystal grain size, one or both of Nb and V may be added to steel according to the present invention. When the content of Nb is below 0.005% or that of V is below 0.03%, however, a sufficient effect is not obtained but, on the other hand, when their contents exceed 0.1 and 0.3%, respectively, the effect is saturated and, adversely, ductility is lowered. Hence, their contents are defined as 0.0005 to 0.1% for Nb and 0.03 to 0.3% for V.

[0023] Further, steel according to the present invention may contain one or more of 0.02% or less of Te, 0.02% or less of Ca, 0.01% or less of Zr, 0.035% or less of Mg, 0.15% or less of rare earth elements and 0.1% or less of Y for the purposes of controlling the shape of MnS, preventing cracks and enhancing ductility. Each of these elements forms oxides, and the oxides not only act as nuclei for the formation of MnS but also reform MnS into (Mn, Ca)S, (Mn, Mg) S, etc. Since this makes the sulfides easily stretchable during hot rolling and makes granular MnS disperse in fine grains, ductility is improved and the critical compressibility during cold forging is also improved. On the other hand, when Te is added in excess of 0.02%, Ca in excess of 0.02%, Zr in excess of 0.01%, Mg in excess of 0.035%, Y in excess of 0.1%, and/or rare earth elements in excess of 0.15%, the above effects are saturated and, adversely, ductility is deteriorated as a result of the formation of coarse oxides such as CaO, MgO, etc., clusters of these oxides and the precipitation of hard compounds such as ZrN and the like. For this reason, the contents of these elements are defined as 0.02% or less for Te, 0.02% or less for Ca, 0.01% or less for Zr, 0.035% or less for Mg, 0.1% or less for Y, and 0.15% or less for rare earth elements. Note that the rare earth elements are the elements having the atomic numbers of 57 to 71.

[0024] Here, the Zr content in steel is determined by inductively coupled plasma emission spectrometry (ICP), in a manner similar to the determination of Nb content in steel, after sample treatment in the same manner as specified in Attachment 3 of JIS G 1237-1997. The samples used in the measurement of the examples of the present invention are 2g per steel grade and the calibration curves for the ICP are set so as to be suitable for measuring a very small quantity of Zr. Namely, solutions having different Zr concentrations are prepared by diluting the standard Zr solution so that the Zr concentrations vary from 1 to 200 ppm, and the calibration curves are determined by measuring the amounts of Zr in the solutions. The common procedures related to the ICP are in accordance with JIS K 0116-1995 (General Rules for Emission Spectrometry) and JIS Z 8002-1991 (General Rules for Tolerances of Tests and Analyses).

[0025] Next, the structure of a steel bar or wire rod according to the present invention is explained hereafter.

[0026] The present inventors studied methods to enhance the ductility of a steel bar or wire rod for cold forging and clarified that the key to enhancing the ductility of spheroidizing-annealed steel materials was to make the spheroidizing-annealed structure uniform and fine, and, to this end, it was effective to suppress the ferrite percentage in the structure after hot rolling to a specified percentage or less and make the balance a mixed structure consisting of one or more of fine martensite, bainite and pearlite. For this reason, the ductility of a steel bar or wire rod improves when it undergoes rapid cooling after hot finish rolling and then spheroidizing annealing. However, when a steel bar or wire rod is rapidly cooled and hardened throughout the cross section of the structure, quenching cracks are likely to occur, steel hardness does not decrease even after spheroidizing annealing, cold deformation resistance increases, and thus the service life of cold forging dies becomes shorter. The present inventors discovered that, to solve this problem, it was effective to rapidly cool the surface layer of a steel bar or wire rod after hot finish rolling, then let it recuperate by its sensible heat so as to soften the martensite formed in the surface layer by tempering prior to spheroidizing annealing, and keep the structure of the internal portion softer, as a result of a slower cooling rate, than that of the surface layer, and, by doing so, a steel bar or wire rod for cold forging excellent in ductility after spheroidizing annealing and having low cold deformation resistance could be obtained.

[0027] Fig. 1 is a graph showing the relationship between the distance (mm) from the surface and the hardness (HV) of a steel bar for cold forging (C: 0.48%) according to the present invention having the diameter of 36 mm.

[0028] As shown in Fig. 1, the average hardness of the surface layer is HV 285 and that at the center is HV 190.

The hardness of the center portion is greatly lower than that of the surface, the difference being approximately HV 100.

[0029] As for the structure, as shown in the micrographs (x 400) of the surface layer in Fig. 2(a) and the center in Fig. 2(b), the surface layer is mainly composed of tempered martensite and the center portion mainly of ferrite and pearlite.

[0030] As for the structures obtained after holding the steel bar of Fig. 1 at 745°C for 3 hr. and applying spheroidizing annealing by slow-cooling at a cooling rate of 10°C/hr., as shown in the micrographs (x 400) of the surface in Fig. 3(a) and the center in Fig. 3(b), the structure of the surface is well spheroidized and homogeneous. The hardness after the spheroidizing annealing is approximately HV 130 and the difference in hardness between the surface and the center is as small as about HV 10.

[0031] The steel bar after the spheroidizing annealing was subjected to an upsetting test, under heavy working, at a true strain exceeding 1. However, no cold forging cracks were generated and cold deformation resistance remained at a low level and did not cause any problem in cold forging work.

[0032] Then, the present inventors proceeded with tests and examinations on the relationship between the structure of the surface layer and the hardness of the surface layer and the center portion to clarify the conditions where cracks were not generated even in cold forging.

[0033] As a result, the present inventors discovered the following: cold forging cracks could not be prevented unless the area percentage of ferrite structure was 10% or less, preferably 5% or less in case of cold forging requiring heavy working, at the portion from the surface to the depth of 0.15 times the radius of a steel bar or wire rod, even if the surface layer was composed of a tempered martensite structure (a structure in which ferrite exists in a phase consisting substantially of one or more of martensite, bainite and pearlite); for securing ductility to prevent cracks from occurring during cold forging and deformation resistance from increasing, it was necessary to form a fine and homogeneous structure having a higher percentage of tempered martensite in the surface layer at the stage of an as rolled steel bar or wire rod; and to do so, it was necessary to create a difference in hardness between the surface layer and the center portion at the stage of an as rolled steel bar or wire rod, and it was indispensable to make the average hardness (HV) of the portion from the depth of 0.5 times the radius of the steel bar or wire rod to its center less than the average hardness (HV) of the portion from the surface to the depth of 0.15 times the radius by HV 20 or more, preferably, by HV 50 or more in case of cold forging requiring heavy working.

[0034] Then, when the above steel bar or wire rod is subjected to spheroidizing annealing (SA), obtained is a steel bar or wire rod for cold forging excellent in ductility, wherein the degree of spheroidized structure defined by JIS G 3539 is within No.2 at the portion from the surface to a depth of 0.15 times the radius of the steel bar or wire rod and, in addition, the degree of spheroidized structure is within No. 3 at the portion from a depth of 0.5 times its radius to its center. It was confirmed that the spheroidizing-annealed steel bar or wire rod thus obtained does not develop cold forging cracks even in an upsetting test, under heavy working, with a true strain exceeding 1.

[0035] Note that conventionally known methods for spheroidizing annealing can be employed for the spheroidizing annealing of the present invention.

[0036] In order to obtain a crystal grain size of the surface layer which contributes to the enhancement of ductility, it is enough to make the austenite crystal grain size number (JIS G 0551) before spheroidizing annealing equal to or larger than 8 at the portion from the surface to a depth of 0.15 times the radius of the steel bar or wire rod, and it is preferable to make the number equal to or larger than 9 when better properties are required and, further, equal to or larger than 10 when yet higher properties are required. In addition to the above, after the spheroidizing annealing, it is enough to make the ferrite crystal grain size number (JIS G 3545) equal to or larger than 8 at the portion from the surface to the depth of 0.15 times the radius of the steel bar or wire rod, and it is preferable to make the number equal to or larger than 9 when better properties are required, and, further, equal to or larger than 10 when yet higher properties are required.

[0037] When the crystal grain size numbers are below the above specifications, sufficient ductility is not achieved.

[0038] The method to produce a steel bar or wire rod for cold forging according to the present invention is explained hereafter.

[0039] Fig. 4 is a schematic illustration showing an example of a rolling line employed in the present invention.

[0040] As seen in the figure, a steel having a chemical composition according to any of claims 1 to 5 is heated in a reheating furnace 1 and finish-rolled through a rolling mill train 2, in a manner to control the surface temperature of the steel bar or wire rod to 700 to 1,000°C at the exit from the final rolling mill stand. The temperature at the exit from the final rolling mill stand is measured with a pyrometer 3. Then the finish-rolled steel bar or wire rod 4 is rapidly cooled (preferably, at an average cooling rate of, for example, 30°C/sec. or higher) to a surface temperature of 600°C or lower, preferably 500°C or lower, or more preferably 400°C or lower, with water directly applied to its surface through cooling troughs 5, so that the surface structure may consist mainly of martensite. After passing through the cooling troughs, the surface temperature of the steel bar or wire rod is recuperated to 200 to 700°C (measured with a pyrometer 6) by the sensible heat of its center portion so that the surface structure may consist mainly of tempered martensite.

[0041] The present invention provides that the above process cycle of rapid cooling and recuperation is conducted

at least once or more. This remarkably enhances steel ductility.

[0042] The reason why the surface temperature of the steel material is controlled to 700 to 1,000°C is that low temperature rolling can fine crystal grains and the structure after rapid cooling. When the temperature is 1,000°C or lower, the austenite grain size number in the surface layer is 8; when it is 950°C or lower, the grain size number is 9; and when it is 860°C or lower, the grain size number is 10. When the surface temperature is below 700°C, however, it becomes difficult to reduce the quantity of ferrite in the surface layer, and, for this reason, the surface temperature has to be 700°C or above.

[0043] Note that the direct surface quenching method (DSQ) and the apparatus employed in the present invention are publicly known and were disclosed in Japanese Unexamined Patent Publications No. S62-13523 and No. H1-25918, though the objects of the production in those publications are different from those of the present invention.

[0044] Fig. 5 is a diagram showing CCT curves for explaining the structures of the surface layer and the center portion of a steel bar or wire rod.

[0045] As shown in the figure, when a steel bar or wire rod finish-rolled at a low temperature is rapidly cooled and then recuperated, the structure of the surface layer 7 mainly consists of tempered martensite since the surface layer is cooled more rapidly, while the structure of the center portion 8 consists of ferrite and pearlite since the center portion is cooled more slowly than the surface layer.

[0046] The object of lowering the surface temperature to 600°C or below by rapid cooling and then recuperating the surface temperature to 200 to 700°C by the sensible heat is to make the structure of the surface layer mainly consist of tempered martensite having reduced hardness.

Example

[0047] Examples of the present invention are explained hereafter.

[0048] The steels listed in Tables 1 and 2 were rolled into steel bars and wire rods under the rolling conditions listed in Table 3. The diameters of the rolled products ranged from 36 to 55 mm. The rolled products then underwent spheroidizing annealing and hardening treatment through quenching and tempering. The metallographic structure and material properties of the products were investigated in the as rolled, as spheroidizing-annealed and as quenched and tempered states. The results are shown in Table 3.

[0049] "The portion from the surface to the depth of 0.15 times the radius of the steel bar or wire rod" specified in Claims of the present invention is expressed simply as "surface layer" (e.g., surface layer hardness) in Tables 4 to 6. Likewise, "the portion from the depth of 0.5 times the radius to the center" specified in Claims of the present invention is expressed simply as "center portion" (e.g., center portion hardness) in the tables. The deformation resistance was measured through upsetting tests of columnar test pieces having the same diameter as the rolled products and a height 1.5 times the diameter. The critical compressibility was measured through upsetting tests of the columnar test pieces of the same dimension with a notch 0.8 mm in depth and 0.15 mm in notch apex radius on the surfaces. Test pieces for tensile tests were cut out from the positions corresponding to the surface layer of the rolled products, and the tensile strength and reduction of area, which is an indicator of ductility, of the surface layer were measured through tensile tests. The rolled products of each steel grade underwent any one of the common quenching and tempering (common QT), induction hardening and tempering (IQT) and carburization hardening and tempering (CQT). The induction hardening was conducted at a frequency of 30 kHz. The carburization hardening was conducted under the condition of a carbon potential of 0.8% and 950°C x 8 hr.

[0050] As is clear from Tables 4 to 6, the examples according to the present invention demonstrate remarkably better values of the critical compressibility and the reduction of area, which are indicators of steel ductility, compared with the comparative examples having the same carbon contents, and their deformation resistance and the hardness after the quenching and tempering are satisfactory.

[0051] Next, the steels listed in Table 7 were rolled into steel bars and wire rods 36 to 50 mm in diameter under the rolling conditions listed in Table 3 as in the above examples, spheroidizing-annealed, and then hardened through quenching and tempering. Table 8 shows the investigation results of their structure and material properties. Comparing the examples of Table 8 and the comparative examples of Table 6, the examples according to the present invention demonstrate remarkably better values of the critical compressibility and the reduction of area, which are indicators of steel ductility, compared with the comparative examples having the same carbon contents, and their deformation resistance and the hardness after the quenching and tempering are satisfactory.

Table 1

(mass %)

Classification	Steel	C	Si	Mn	S	Al	B	P	N	O	Ti	Ni	Cr	Mo	Nb	V	Te	Ca
Invented steels	1	0.25	0.25	1.10	0.008	0.062	0.0020	0.020	0.0035	0.0014	-	-	-	-	-	-	-	-
	2	0.33	0.23	0.80	0.013	0.061	0.0019	0.014	0.0044	0.0014	-	-	-	-	-	-	-	-
	3	0.43	0.24	1.34	0.009	0.060	0.0020	0.012	0.0043	0.0007	-	-	-	-	-	-		-
	4	0.25	0.23	1.11	0.009	0.027	0.0019	0.009	0.0042	0.0009	0.040	-	-	-	-	-	-	-
	5	0.34	0.22	0.82	0.014	0.027	0.0018	0.016	0.0045	0.0009	0.034	-	-	-	-	-	-	-
	6	0.43	0.23	1.38	0.008	0.025	0.0020	0.012	0.0048	0.0012	0.028	-	-	-	-	-	-	-
	7	0.35	0.04	1.08	0.011	0.033	0.0020	0.014	0.0045	0.0008	0.033		-	-	-	-	-	-
	8	0.45	0.04	1.01	0.009	0.028	0.0019	0.011	0.0042	0.0010	0.028	-	-	-	-	-	-	-
	9	0.48	0.04	1.04	0.012	0.030	0.0020	0.012	0.0047	0.0011	0.026	-	-	-	-	-	-	-
	10	0.53	0.04	1.02	0.007	0.029	0.0020	0.012	0.0045	0.0012	0.027	-	-	-	-	-	-	-
	11	0.25	0.24	0.51	0.008	0.059	0.0018	0.009	0.0038	0.0008	-	-	0.70	-	-	-	-	-
	12	0.45	0.04	0.30	0.006	0.064	0.0020	0.014	0.0036	0.0007	-	-	0.27	-	-	-	-	-
	13	0.53	0.04	0.31	0.010	0.063	0.0018	0.008	0.0048	0.0013	-	-	0.28	-	-	-	-	-
	14	0.40	0.05	0.38	0.009	0.062	0.0019	0.012	0.0038	0.0013	-	-	1.06	-	-	-	-	-
	15	0.35	0.04	0.40	0.010	0.066	0.0018	0.008	0.0038	0.0015	-	-	1.03	0.17	-	-	-	-
	16	0.24	0.25	0.52	0.007	0.028	0.0019	0.009	0.0038	0.0007	0.038	-	0.71	-	-	-	-	-
	17	0.33	0.24	0.85	0.011	0.028	0.0019	0.014	0.0045	0.0009	0.030	-	0.12	-	-	-		-
	18	0.43	0.25	1.31	0.006	0.025	0.0021	0.012	0.0047	0.0011	0.026	-	0.12	-	-	-	-	-
	19	0.40	0.24	0.82	0.012	0.028	0.0019	0.012	0.0039	0.0012	0.030	-	1.14	-	-	-	-	-
	20	0.35	0.25	0.81	0.008	0.028	0.0018	0.011	0.0046	0.0009	0.034	-	1.04	0.16	-	-	-	-
	21	0.35	0.05	0.31	0.010	0.027	0.0021	0.008	0.0043	0.0008	0.034		0.30	-	-	-	-	-
	22	0.45	0.04	0.30	0.007	0.028	0.0019	0.013	0.0045	0.0012	0.031	-	0.31	-	-	-	-	-
	23	0.53	0.05	0.30	0.000	0.029	0.0020	0.010	0.0051	0.0010	0.029	-	0.30	-	-	-	-	-
	24	0.58	0.04	0.28	0.007	0.091	0.0022	0.010	0.0047	0.0009	0.031	-	0.31	-	-	-	-	-
	25	0.35	0.04	0.41	0.010	0.027	0.0018	0.011	0.0046	0.0010	0.030	-	1.04	0.16	-	-	-	-
	26	0.40	0.05	0.40	0.011	0.030	0.0019	0.012	0.0049	0.0013	0.032	-	1.02	-	-	-	-	-
	27	0.32	0.05	0.34	0.007	0.028	0.0020	0.015	0.0049	0.0014		-	-	-	0.018	0.15	-	-
	28	0.40	0.04	1.01	0.009	0.028	0.0019	0.011	0.0042	0.0010	0.028	-	-	-	-	-	0.0024	-
	29	0.45	0.04	1.14	0.012	0.030	0.0020	0.012	0.0047	0.0011	0.026	-	-	-	0.020	-	0.0030	-
	30	0.45	0.05	0.30	0.007	0.030	0.0019	0.012	0.0037	0.0011	0.030	-	0.30	-		-	0.0031	-
	31	0.43	0.23	1.35	0.012	0.031	0.0020	0.013	0.0047	0.0012	0.027	-	0.11	-	-	-	0.0025	-
	32	0.40	0.25	0.80	0.007	0.027	0.0020	0.012	0.0038	0.0013	0.030	-	1.12	-	-	-	0.0026	-

Table 2

(mass %)

Classi-fication	Steel	C	Si	Mn	S	Al	B	P	N	O	Ti	Ni	Cr	Mo	Nb	V	Te	Ca
Invented steels	33	0.20	0.25	0.81	0.007	0.060	0.0021	0.012	0.0039	0.0008	-	-	1.12		-	-	-	-
	34	0.15	0.23	0.79	0.010	0.069	0.0020	0.014	0.0039	0.0013	-	-	1.07	0.17	-	-	-	-
	35	0.20	0.04	0.40	0.009	0.061	0.0021	0.012	0.0041	0.0010	-	-	1.10	0.04	-		-	-
	36	0.20	0.25	0.81	0.011	0.030	0.0021	0.012	0.0048	0.0008	0.040	-	1.10	-	-	-		-
	37	0.15	0.23	0.79	0.007	0.029	0.0020	0.014	0.0036	0.0013	0.038	-	1.12	0.17	-	-	-	-
	38	0.20	0.04	0.40	0.009	0.031	0.0021	0.012	0.0048	0.0010	0.041	-	1.10	0.04	-	-	-	-
	39	0.20	0.04	0.41	0.011	0.029	0.0019	0.013	0.0040	0.0012	0.039	-	1.11	0.16	-	-	-	-
	40	0.20	0.05	0.41	0.007	0.028	0.0020	0.010	0.0037	0.0009	0.038	0.54	0.44	0.16	-	-	-	-
	41	0.20	0.04	0.41	0.011	0.065	0.0019	0.013	0.0039	0.0012	-	-	1.12	0.17	0.028	-	-	-
	42	0.20	0.04	0.42	0.007	0.062	0.0021	0.012	0.0042	0.0009	-	-	1.14	0.05	0.029	-	-	-
	43	0.19	0.24	0.84	0.007	0.030	0.0020	0.013	0.0037	0.0009	0.032	-	1.13	-	0.024	-	-	-
	44	0.20	0.26	0.82	0.012	0.029	0.0020	0.011	0.0038	0.0011	0.030	-	1.11	0.16	0.023	-	-	-
	45	0.20	0.04	0.42	0.007	0.031	0.0021	0.012	0.0044	0.0010	0.030	-	1.08	0.05	0.023	-	-	-
	46	0.20	0.04	0.42	0.010	0.029	0.0019	0.013	0.0041	0.0009	0.029	-	1.09	0.17	0.022	-	-	-
	47	0.19	0.05	0.42	0.006	0.031	0.0019	0.012	0.0037	0.0010	0.031	0.60	0.46	0.17	0.022	-	-	-
	48	0.20	0.05	0.40	0.009	0.031	0.0021	0.012	0.0048	0.0010	0.035	-	1.10	-	0.017	0.10	-	-
	49	0.19	0.24	0.84	0.012	0.030	0.0020	0.013	0.0038	0.0009	0.041	-	1.13	-	-	-	0.0028	-
	50	0.15	0.04	0.43	0.008	0.029	0.0019	0.011	0.0040	0.0012	0.029	-	1.09	0.04	0.023	-	-	0.0030
	51	0.20	0.05	0.42	0.013	0.030	0.0022	0.013	0.0037	0.0011	0.030	-	1.12	0.04	0.021	-	0.025	-
	52	0.19	0.04	0.44	0.007	0.029	0.0020	0.011	0.0038	0.0010	0.029	-	1.11	0.05	0.025		0.023	0.0029
	53	0.48	0.04	0.30	0.006	0.030	0.0020	0.012	0.0040	0.0011	-	-	-	-	-	-		-
	54	0.53	0.04	0.31	0.008	0.029	0.0019	0.012	0.0037	0.0012	-	-	-	-	-	-	-	
	55	0.47	0.05	0.29	0.007	0.028	0.0020	0.012	0.0040	0.0011	0.025	-	-	-	-	-	-	-
	56	0.53	0.04	0.30	0.008	0.029	0.0020	0.012	0.0038	0.0012	0.027	-	-	-	-	-	-	-
Compara-tive steels	57	0.34	0.22	0.80	0.013	0.029	-	0.014	0.0042	0.0014	-	-	-	-	-	-	-	-
	58	0.45	0.23	0.78	0.008	0.030	-	0.012	0.0051	0.0009	-	-	-	-	-	-	-	-
	59	0.53	0.23	0.74	0.009	0.027		0.009	0.0050	0.0009	-	-	-	-	-	-	-	-
	60	0.40	0.25	0.82	0.009	0.030	-	0.009	0.0054	0.0013	-	-	1.06	-	-	-	-	-
	61	0.35	0.23	0.79	0.010	0.026	-	0.013	0.0046	0.0015	-	-	1.03	0.17	-	-	-	-
	62	0.20	0.24	0.82	0.010	0.030	-	0.012	0.0152	0.0007	-	-	1.12	-	-	-	-	-
	63	0.15	0.22	0.80	0.013	0.029	-	0.014	0.0134	0.0013	-	-	1.10	0.16	-	-	-	-

Table 3

Classification	Rolling condition	Steel surface temperature at exit from finish rolling °C	Number of rapid cooling-recuperation cycles	Steel surface temperature immediately after rapid cooling (average temperature in case of II)	Recuperation temperature (average temperature in case of II)
Examples of present invention	I	740 - 960	1	About 200°C	400 - 600°C
	II	750 - 950	7	About 500°C	390 - 660
Comparative examples	III	880 - 950	Air-cooled after hot rolling		

Table 4

Classification	Level	Steel No.	Rolling condition	Structure and properties of bar or wire rod					Structure and properties after spheroidizing annealing								Surface hardness after QT HV		
				Area percentage of ferrite in surface layer %	Surface layer hardness HV	Center portion hardness HV	Hardness difference between surface layer and center portion HV	γ grain size number of surface layer	Degree of spheroidized structure of surface layer	Degree of spheroidized structure of center portion	Ferrite grain size number of surface layer	Deformation resistance MPa	Critical compressibility %	Surface layer hardness HV	Tensile strength MPa	Reduction of area %	Common QT	IQT	CQT
Specification range of invention				≤ 10%			≥ 20	≥ 8	≤ No. 2	≤ No. 3	≥ 8								
Examples of invention 1	1	1	I	4	220	164	56					630	62.4	115	350	92	231		
	2	53	I	0	268	203	65					720	56.5	131	483	77		650	
	3	54	I	0	312	225	87					763	51.2	147	553	73		698	
Examples of invention 2	4	6	I	0	276	195	81					709	57.3	127	462	82		639	
	5	10	I	0	312	225	87					763	51.2	147	523	74		696	
	6	55	I	0	270	205	65					720	56.5	131	483	78		650	
	7	56	II	0	312	225	87					753	51.2	147	553	74		694	
Examples of invention 3	8	13	I	0	312	225	87					763	51.2	147	533	74		696	
	9	17	I	0	264	199	65					658	57.3	128	418	88		622	
	10	22	I	0	266	185	81					705	57.3	127	462	82		639	
	11	24	II	0	299	228	71					750	53.2	139	522	73		692	
Examples of invention 4	12	27	I	0	297	234	63					738	52.5	139	520	72		924	
Examples of invention 5	13	29	I	0	272	203	69					748	54.4	142	513	76		682	
	14	32	I	0	273	206	67					744	55.2	128	471	82		657	
Examples of invention 3	15	33	I	0	341	232	109					655	60.8	119	408	91			804
	16	37	I	0	323	222	101					647	62.2	112	403	91			802
	17	39	I	0	323	210	113					627	61.0	115	404	92			811
Examples of invention 4	18	41	II	0	340	238	102					632	63.4	118	407	92			801
	19	43	I	0	315	212	103					644	61.8	121	405	92			778
	20	46	I	0	277	200	77					645	62.4	119	411	91			780
Examples of invention 5	21	50	I	0	302	214	88					651	62.6	121	409	91			805

Table 5

Classification	Level	Steel No.	Rolling condition	Structure and properties of bar or wire rod: Area percentage of ferrite in surface layer %	Surface layer hardness HV	Center portion hardness HV	Hardness difference between surface layer and center portion HV	γ grain size number of surface layer	Structure and properties after spheroidizing annealing: Degree of spheroidized structure of surface layer	Degree of spheroidized structure of center portion	Ferrite grain size number of surface layer	Deformation resistance MPa	Critical compressibility %	Surface layer hardness HV	Tensile strength MPa	Reduction of area %	Surface hardness after QT HV: Common QT	IQT	CQT
Specification range of invention				≦ 10%			≧ 20	≧ 8	≦ No. 2	≦ No. 3	≧ 8								
Examples of invention 6	22	3	I	0	266	185	81	10.4				699	58.3	128	462	83		639	
	23	4	I	4	203	147	56	10.9				620	61.4	117	402	93	232		
	24	7	I	3	262	200	62	10.5				660	59.2	125	415	89		620	
	25	14	I	0	265	197	68	10.2				742	56.4	128	473	84		653	
	26	19	II	0	275	207	68	9.9				742	57.4	128	473	84		653	
	27	23	I	0	302	215	87	10.8				763	52.2	147	539	75		689	
	28	28	I	0	284	211	73	9.5				735	56.2	124	466	83		658	
	29	31	I	0	272	203	69	10.4				738	54.4	140	513	77		682	
	30	34	I	0	323	222	101	11.8				647	62.2	122	423	91			802
	31	36	I	0	341	232	109	10.8				655	60.8	119	418	91			804
	32	44	II	0	340	238	102	11.2				632	62.4	115	417	90			801
	33	52	I	0	302	214	88	10.4				651	62.6	120	419	91			805
Examples of invention 8	34	2	I	3	262	200	62		1	2		660	57.2	124	415	87		620	
	35	5	I	3	262	200	62		1	2		660	57.2	124	415	88		620	
	36	8	I	0	266	185	81		1	2		699	56.3	128	462	82		639	
	37	11	I	4	203	147	56		1	2		620	61.4	115	394	92	233		
	38	15	I	0	261	199	63	10.4	1	2		662	57.3	126	403	84		620	
	39	18	I	0	266	185	81		1	2		709	58.9	123	462	82		639	
	40	21	I	3	262	200	62		1	2		660	57.2	124	415	84		620	
	41	26	I	0	271	199	63	10.4	1	2		662	57.3	124	423	87		615	
	42	35	I	0	335	226	109		1	2		657	60.2	124	422	90			812
	43	45	II	0	285	200	85		1	2		635	61.3	121	416	91			794
	44	48	II	0	275	205	70	9.2	1	2		644	61.6	120	422	87			795
	45	51	I	0	302	214	88		1	2		651	62.6	120	419	89			805

Table 6

Classification	Level	Steel No.	Rolling condition	Structure and properties of bar or wire rod: Area percentage of ferrite in surface layer %	Surface layer hardness HV	Center portion hardness HV	Hardness difference between surface layer and center portion HV	γ grain size number of surface layer	Structure and properties after spheroidizing annealing: Degree of spheroidized structure of surface layer	Degree of spheroidized structure of center portion	Ferrite grain size number of surface layer	Deformation resistance MPa	Critical compressibility %	Surface layer hardness HV	Tensile strength MPa	Reduction of area %	Surface hardness after QT HV: Common QT	IQT	CQT
Specification range of invention				≦ 10%			≧ 20	≧ 8	≦ No. 2	≦ No. 3	≧ 8								
Examples of invention 9	46	9	I	0	270	205	85		1	2	10.1	710	55.5	131	483	78		690	
	47	12	I	0	256	185	81		1	2	10.5	709	57.3	128	462	92		639	
	48	16	I	0	261	200	61		1	2	9.7	628	63.8	119	392	92	235		
	49	20	I	0	261	199	63	10.7	1	2	10.2	652	57.3	124	423	88		614	
	50	25	I	0	275	207	68		1	2	9.9	742	55.4	128	373	83		653	
	51	30	I	0	267	186	81		1	2	9.8	712	57.2	130	478	80		641	
	52	38	II	0	321	211	110		1	2	10.3	635	62.4	118	417	91			809
	53	40	I	0	345	236	109		1	2	10.4	647	60.2	120	412	90			812
	54	42	I	0	325	222	103		1	2	9.7	634	61.8	119	405	92			778
	55	47	II	0	335	226	100		1	2	9.9	657	60.2	119	412	91			812
	56	49	I	0	325	220	105	10.0	1	2	9.5	643	61.6	121	415	91			782
Comparative examples	57	57	III	62	191	183	8		3	4		730	46.2	152	515	76		536	
	58	58	III	47	215	207	8		3	4		769	45.3	156	562	70		561	
	59	59	III	34	224	219	5		4	4		833	42.2	175	633	61		592	
	60	60	III	30	255	244	11		3	4		812	45.4	157	573	72		578	
	61	61	III	26	272	258	14		2	3		732	47.3	155	623	71		563	
	62	62	III	52	199	192	7		3	4		725	47.8	148	528	77			804
	63	63	III	36	224	214	10		3	4		726	47.2	151	543	77			802

Common QT: Quenching at 900°C + tempering at 550°C;
IQT: induction hardening + tempering at 170°C;
CQT: carburization hardening + tempering at 170°C.

Table 7

(mass %)

Steel	C	Si	Mn	S	Al	B	P	N	O	Ti	Cr	Mo	Nb	Te	Zr	Mg	Y	Rare earth element
71	0.45	0.04	1.30	0.014	0.058	0.0018	0.015	0.0042	0.0013	-	-	-			0.0024	-	-	-
72	0.43	0.04	1.05	0.008	0.034	0.0019	0.012	0.0048	0.0009	0.026	-	-	-	0.0194	0.0033	-	-	-
73	0.45	0.04	0.46	0.015	0.032	0.0021	0.014	0.0047	0.0011	0.025	-		-	-	-	0.0158	-	-
74	0.45	0.05	0.35	0.007	0.066	0.0021	0.015	0.0040	0.0008	-	0.28		-	-	-	-	-	0.024
75	0.44	0.04	0.32	0.010	0.033	0.0019	0.012	0.0047	0.0012	0.030	0.33	-	-		0.0022	0.0172	-	-
76	0.20	0.04	0.43	0.008	0.035	0.0030	0.013	0.0044	0.0012	0.027	1.04	0.05	0.025	-	0.0036	-	-	-
77	0.19	0.04	0.50	0.013	0.037	0.0028	0.014	0.0046	0.0013	0.025	1.12	0.05	0.023	-		0.0235	-	-
78	0.45	0.04	0.48	0.013	0.035	0.0018	0.016	0.0045	0.0012	0.024	-	-	-	-	-	-	0.018	-

Table 8

Classification	Level	Steel No.	Rolling condition	Structure and properties of bar or wire rod					Structure and properties after spheroidizing annealing								Surface hardness after QT HV		
				Area percentage of ferrite in surface layer %	Surface layer hardness HV	Center portion hardness HV	Hardness difference between surface layer and center portion HV	γ grain size number of surface layer	Degree of spheroidized structure of surface layer	Degree of spheroidized structure of center portion	Ferrite grain size number of surface layer	Deformation resistance MPa	Critical compressibility %	Surface layer hardness HV	Tensile strength MPa	Reduction of area %	Common QT	IQT	CQT
Specification range of invention				≦ 10%			≧ 20	≧ 8	≦ No. 2	≦ No. 3	≧ 8								
Examples of invention 8	71	71	I	0	268	187	81		1	2		697	58.7	124	460	84		642	
	72	72	I	0	263	181	82		1	2		694	56.0	129	464	81		638	
	73	73	I	0	269	184	85	9.8	1	2		695	56.6	127	463	83	292		
Examples of invention 9	74	74	I	0	264	181	83	10.5	1	2	9.8	701	56.8	125	465	90		645	
	75	75	I	0	268	180	88	11.3	1	2	10.4	707	56.8	128	460	83		653	
	76	76	II	0	287	194	93	10.7	1	2	10.7	632	60.8	119	417	90			802
	77	77	II	0	288	195	93	11.2	1	2	9.7	637	61.0	123	414	93			807
	78	78	I	0	271	186	85	10.0	1	2	10.0	698	56.0	129	464	82	287		

Common QT: Quenching at 900°C + tempering at 550°C;
IQT: induction hardening + tempering at 170°C;
CQT: carburization hardening + tempering at 170°C.

Industrial Applicability

[0052] A steel bar or wire rod for cold forging according to the present invention is a steel bar or wire rod for cold forging excellent in ductility after spheroidizing annealing and capable of preventing the occurrence of cracking in the steel material during cold forging, which cracking has so far been a problem in the cold forging after spheroidizing annealing. Since the present invention makes it possible to manufacture forged machine components requiring heavy working by cold forging, it brings about remarkable advantages of great productivity improvement and energy saving.

Claims

1. A steel bar or wire rod for cold forging excellent in ductility after spheroidizing annealing, having a chemical composition comprising, in mass,

   0.1 to 0.65% of C,
   0.01 to 0.5% of Si,
   0.2 to 1.7% of Mn,
   0.001 to 0.15% of S,
   0.015 to 0.1% of Al,
   0.0005 to 0.007% of B, and
   the restricted elements of
   0.035% or less of P,
   0.01% or less of N and
   0.003% or less of O,
   with the balance consisting of Fe and unavoidable impurities, **characterized in that**: the area. percentage of ferrite structure is 10% or less at the portion from the surface to a depth of 0.15 times the radius of the steel bar or wire rod; the other portion consists substantially of one or more of martensite, bainite and pearlite; and further the average hardness of the portion from the depth of 0.5 times its radius to its center is less than the hardness of its surface layer (the portion from the surface to the depth of 0.15 times the radius) by HV 20 or more.

2. A steel bar or wire rod for cold forging excellent in ductility after spheroidizing annealing according to claim 1, **characterized by** further containing 0.2 mass % or less of Ti.

3. A steel bar or wire rod for cold forging excellent in ductility after spheroidizing annealing according to claim 1 or 2, **characterized by** further containing, by mass, one or more of

   3.5% or less of Ni,
   2% or less of Cr and
   1% or less of Mo.

4. A steel bar or wire rod for cold forging excellent in ductility after spheroidizing annealing according to any one of claims 1 to 3, **characterized by** further containing, by mass, one or both of

   0.005 to 0.1% of Nb and
   0.03 to 0.3% of V.

5. A steel bar or wire rod for cold forging excellent in ductility after spheroidizing annealing according to any one of claims 1 to 4, **characterized by** further containing, by mass, one or more of

   0.02% or less of Te,
   0.02% or less of Ca,
   0.01% or less of Zr,
   035% or less of Mg,
   0.1% or less of Y and
   0.15% or less of rare earth elements.

6. A steel bar or wire rod for cold forging excellent in ductility after spheroidizing annealing according to any one of

claims 1 to 5, **characterized in that** the austenite grain size number according to Japanese Industrial Standard (JIS) is 8 or larger at the portion from the surface to the depth of 0.15 times the radius of the steel bar or wire rod.

7. A method to produce a steel bar or wire rod for cold forging excellent in ductility after spheroidizing annealing, **characterized by** finish-hot-rolling a steel having a chemical composition specified in any one of claims 1 to 5 in a manner to control its surface temperature to 700 to 1,000°C at the exit from the final finish rolling stand and then subjecting it to at least one or more process cycles consisting of rapid cooling to a surface temperature of 600°C or below and recuperation by its sensible heat to a surface temperature of 200 to 700°C, so that the area percentage of ferrite structure is 10% or less at the portion from the surface to the depth of 0.15 times the radius of the steel bar or wire rod, the other portion consists substantially of one or more of martensite, bainite and pearlite, and further the average hardness of the portion from the depth of 0.5 times its radius to its center is softer than the hardness of its surface layer (the portion from the surface to the depth of 0.15 times the radius) by HV 20 or more.

8. A steel bar or wire rod for cold forging excellent in ductility, **characterized in that** the steel bar or wire rod is subjected to spheroidizing annealing as in any one of claims 1 to 6, the degree of spheroidized structure defined by JIS G 3539 is within No. 2 at the portion from the surface to the depth of 0.15 times the radius of the steel bar or wire rod and, in addition, the degree of spheroidized structure is within No. 3 at the portion from the depth of 0.5 times its radius to its center.

9. A steel bar or wire rod for cold forging excellent in ductility according to claim 8, **characterized in that** the ferrite grain size number under JIS is 8 or larger at the portion from the surface to the depth of 0.15 times the radius of the steel bar or wire rod.

Fig.1

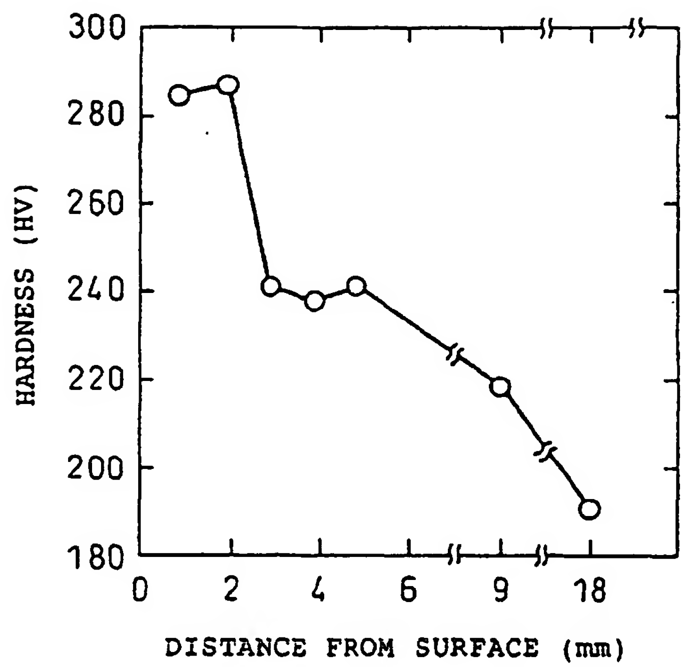

300
280
260
240
220
200
180
HARDNESS (HV)
0
2
4
6
9
18
DISTANCE FROM SURFACE (mm)

Fig. 2(a)

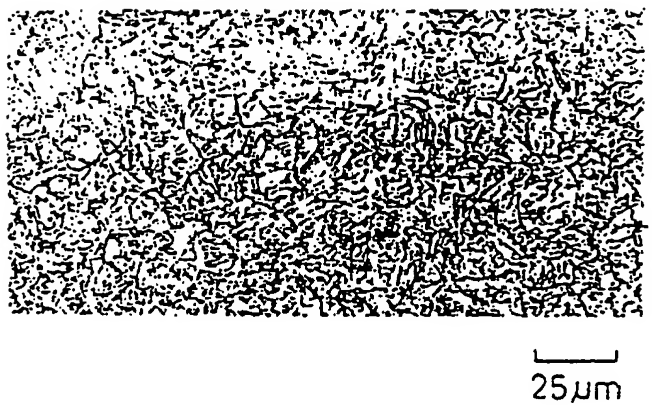


Fig. 2(b)

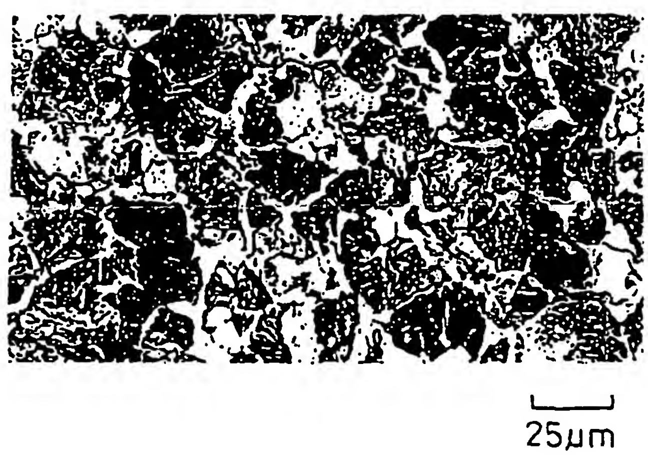
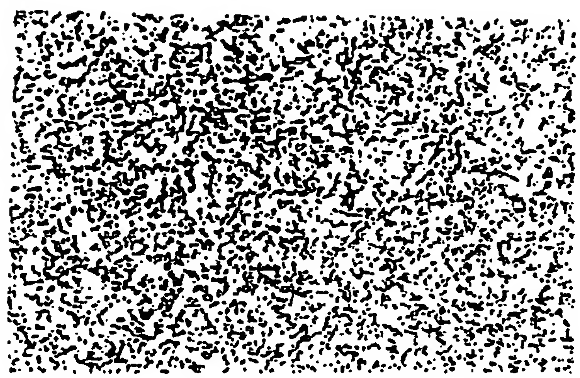


Fig.3(a)



25µm

Fig.3(b)

25µm

Fig. 4

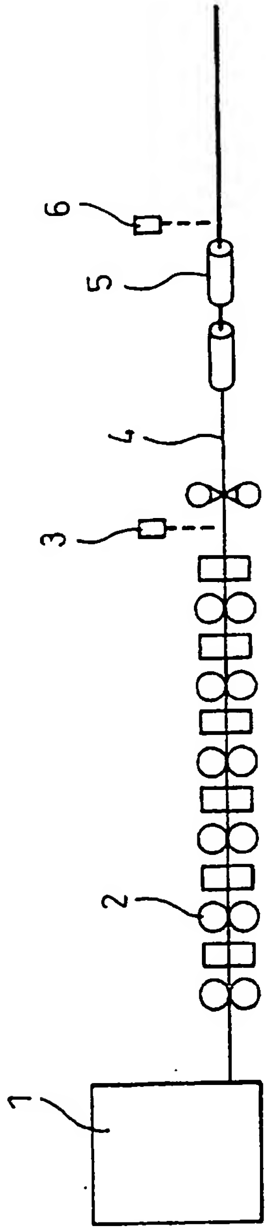


Fig.5(a)

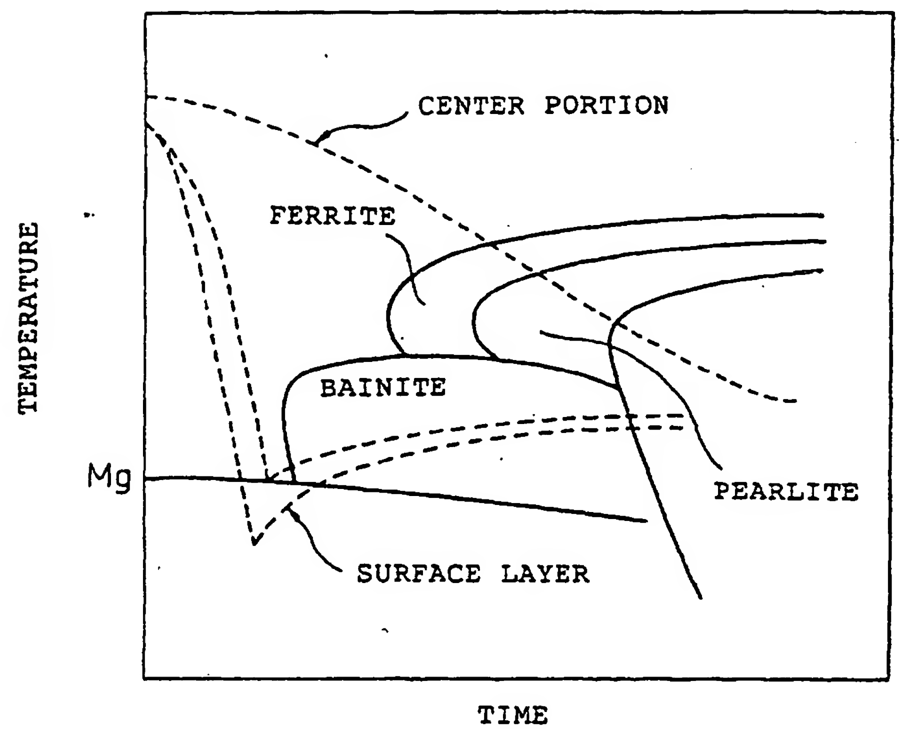
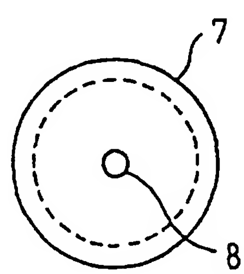

CENTER PORTION
FERRITE
TEMPERATURE
BAINITE
Mg
PEARLITE
SURFACE LAYER
TIME

Fig.5(b)


7
8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP00/09166

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl[7] C22C 38/06
C21D 8/06
C21D 9/52
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
Int.Cl[7] C22C 38/00-38/06
C21D 8/06
C21D 9/52

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Jitsuyo Shinan Koho 1926-1996 Toroku Jitsuyo Shinan Koho 1994-2001
Kokai Jitsuyo Shinan Koho 1971-2001 Jitsuyo Shinan Toroku Koho 1996-2001

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
JOIS
WPI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP, 9-287056, A (Toa Steel Co., Ltd.), 04 November, 1997 (04.11.97), page 2 (Family: none)	1-9
A	JP, 7-268546, A (Sumitomo Metal Industries, Ltd.), 17 October, 1995 (17.10.95), page 2 (Family: none)	1-9
A	JP, 62-139817, A (Kawasaki Steel Corporation), 23 June, 1987 (23.06.87), page 1 (Family: none)	1-9
A	EP, 0508237, A (Bethlehem Steel Corporation), 14 October, 1992 (14.10.92), pages 8 to 9 & JP, 7-34184, A (Bethlehem Steel Corp.), 03 February, 1995 (03.02.95), page 2	1-9
A	Zairyou to Process, Vol.4 (1991) No.3-2040 Toshizo TARUI et al., "Chokusetsu Nanshitsuka Senzai no Kyoudo Ensei no oyobosu Goukin Genso no Eikyou"	1-9

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
05 April, 2001 (05.04.01)	17 April, 2001 (17.04.01)
Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (July 1992)